H - Digital ENG 2 GHz Field Test with Extensive Multi-Path:

When the subject of Digital Video being applied to 2 GHz ENG microwave systems is suggested, the immediate response by many ENG operators is that Digital Video will never work for ENG because they are typically faced with non-engineered paths in which many shots are made using multiple bounces in high multi-path environments and these conditions will cause the picture to freeze thus losing the shot, and some picture is better than no picture. Furthermore, it has been suggested that moderately long STL paths will be severely effected by multi-path and selective fading.

To start to answer some of these questions, NUCOMM has recently completed testing of its 2 GHz ENG Digital Video microwave system in New York City. New York city was chosen because it represents one of the most severe and challenging environments for ENG operation. The results as given in this section were startingly successful to all who participated. The principle objectives of the field tests were:

Digital ENG Field Test

- Test reliability and feasibility of digital MPEG-2 compression and QPSK modulation to digitally transmit an ENG microwave signal under various multi-path conditions.
- Compare the audio video quality of the digital signal with a typical analog FM signal
- Assess how much forward error correction is required to ensure robustness of digital signal transmission in multi-path environments.

I want to acknowledge and thank New York City FOX station WNYW-TV and in particular Rich Paleski for providing the ENG truck, their Empire State Building Central Receive site as well as studio recording equipment and personnel. Rich is a seasoned New York ENG engineer well acquainted with the many difficult multi-bounce and multi-path ENG shots in that city. I would also like to recognize and thank the WEGENER corporation who supplied the Encoding and IRD equipment.

The equipment configuration for this test is shown in Figure 10. The Analog transmitter was a NURAD 10 Watt model PT1. Its output was padded down for an output of 3 Watts. The Digital transmitter was a NUCOMM DIGALOG FT6. Its power output was 1.5 Watts. The power amplifier on the mast at the antenna could not be used because it was operated in saturation and caused excessive spectrum spreading. The antenna was connected directly to the transmitters through 50 feet of Andrew ½ inch flexible coax and had a measured loss of 3 dB. The antenna was a NURAD silhouetta antenna mounted on a pan and tilt. To ensure stress testing the digital encoder, a difficult 2.5 minute video clip of a pre-recorded hockey game on Betacam-SP was used as source material that included fast camera panning, fast action, high color contrast, and saturated colors.

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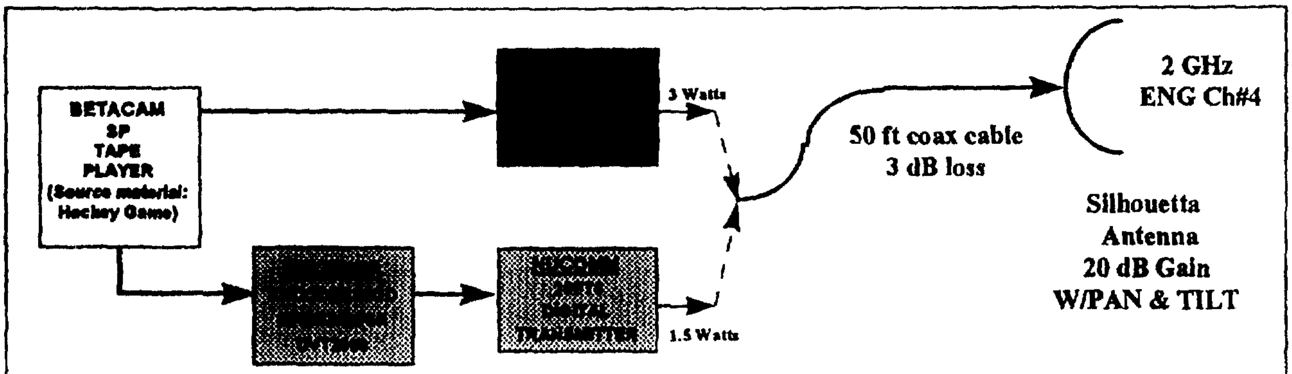
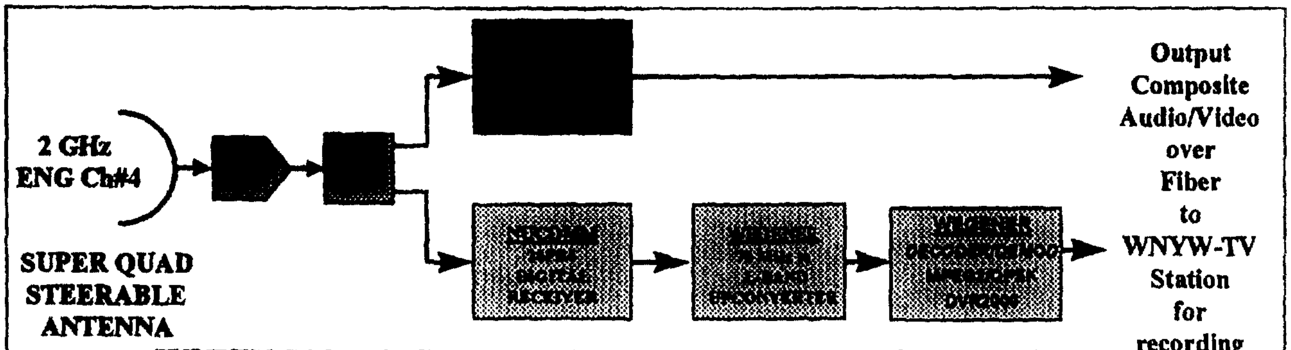
System Components and Parameters

- Analog Transmission
  - Nurad 20PT1 Transmitter, operating at ~3 Watts
  - 17 MHz bandwidth
- Digital Transmission
  - Wegener DVT 2000 MPEG-2 Digital Encoder and QPSK Modulator
  - Nucomm 20FT6 Digital Transmitter, operating at ~1.5 Watts
  - Tested encoding rates from 9 to 15 Mbps
  - Tested forward error correction rates of 1/2, 2/3, 3/4, and 7/8
- 3 Transmission Paths
  - Case 1: Direct Line-of-Sight Transmission
  - Case 2: Moderate multi-path (One Bounce + Reflections)
  - Case 3: Extreme multi-path (Multiple Bounces + Reflections)



WNYW-TV - ENG VAN-TRANSMITTER CONFIGURATION



WNYW-TV - ENG CENTRAL RECEIVE CONFIGURATION at the EMPIRE STATE BUILDING

Figure 10

At the Empire State Building the output from a steerable Superquad antenna was divided and fed both the NURAD analog receiver and the NUCOMM DIGALOG FR6 digital receiver simultaneously. The 70 MHz output from the digital receiver

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was upconverted to L Band to feed the IRD decoder. Each of the composite outputs from both the analog and digital receive systems was transmitted back to the studio over an analog fiber link where the outputs were recorded to Betacam SP tape. Both transmitters were operated on the same 2 GHz channel. Operating on two different frequencies could have negated the tests since multi-path effects would be different.

The first three case tests compared the audio and video quality of the 2 GHz analog FM signal with the quality of the digital MPEG-2 compressed and QPSK modulated signal under the following three environments: (1) direct line-of-sight transmission, (2) moderate multi-path transmission, and (3) extreme multi-path transmission. In each case, the ENG truck was located at E. 90th St. and 5th Ave. and the receive site was the Empire State Building located at E. 33-34th St. and 5th Ave. The antennas on both the transmit and receive sites were steered accordingly to establish the appropriate transmission environment. Figures 11, 12 and 13 show the direction of the ENG shots for each of the three cases respectively. The procedure for setting up each test was to first establish the analog shot geometry and picture quality. The resultant analog video picture was recorded for 2.5 minutes. Then, without moving the antennas, the digital transmitter was connected and the test repeated. Each digital test was conducted using the data rates and FEC shown in the accompanying table.

Digital ENG Test Site

ENG Transmit Truck: E. 90th & 5th Ave.

Empire Receive Site: E. 33-34th & 5th Ave.

WNYW-TV Station: E. 67th & 2nd-3rd Ave.

Test Case 1:

The first test was a line-of-sight shot, as shown in Figure 11, to make sure that the system was working properly. Both analog and digital transmissions overall produced good pictures for each configuration as shown in the table and accompanying the split screen pictures. Although the analog signal is strong, the upper analog portion shows that there were still some multi-path and ghosting artifacts, where the lower digital portion of the picture shows no sign of multi-path or ghosting.

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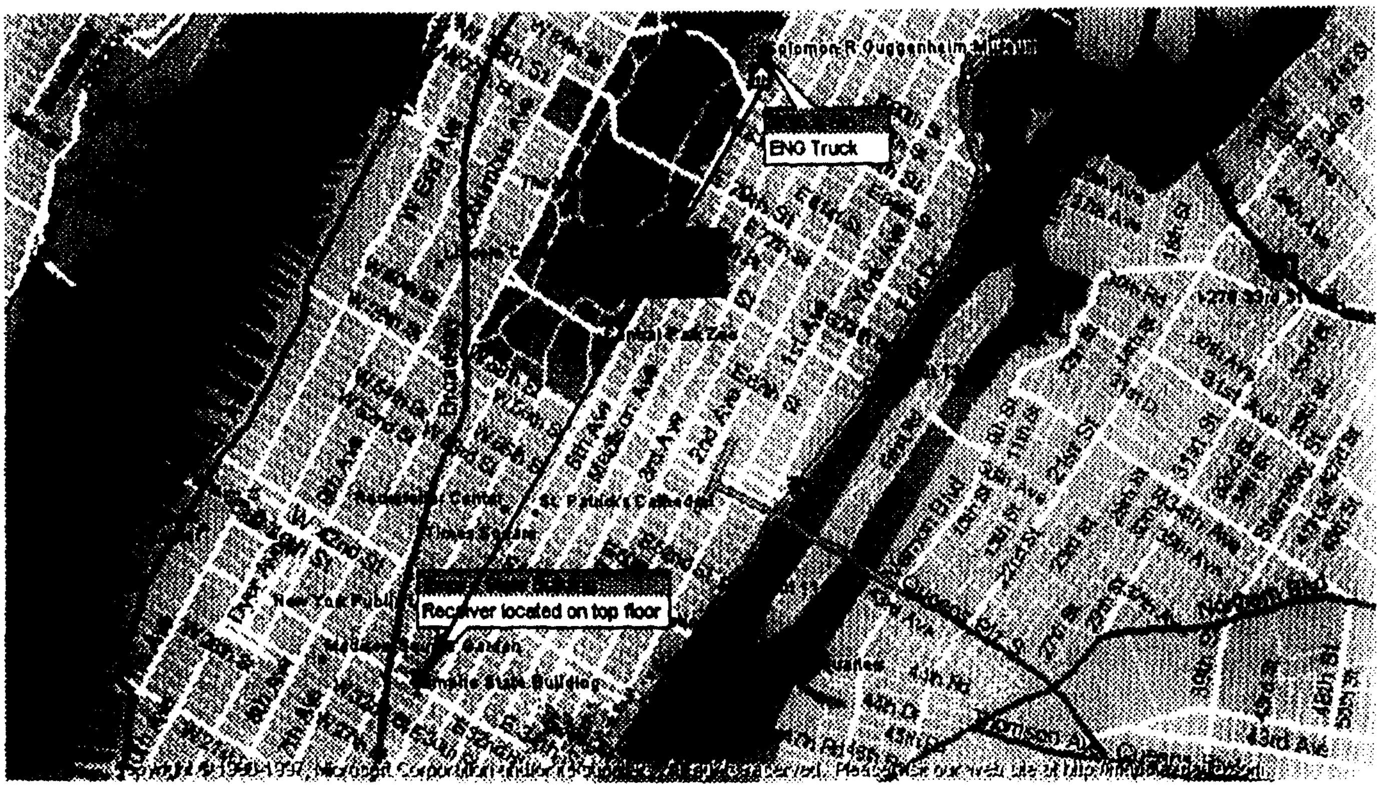
Case 1: Direct Line-of-Sight Transmission



Strong Analog Signal
Very Good Digital Picture
Figure 11

Test Results for Case 1: Direct Line-of-Sight

Mode	Bit Rate	FEC	BW	Rcv. Signal Level
Analog FM			17 MHz	-25 dBm
Digital	9 Mbps	3/4	8.5 MHz	-28 dBm
	10.5 Mbps	7/8	8.5 MHz	-29 dBm
	12.5 Mbps	3/4	12 MHz	-28 dBm
	15 Mbps	7/8	12 MHz	-28 dBm

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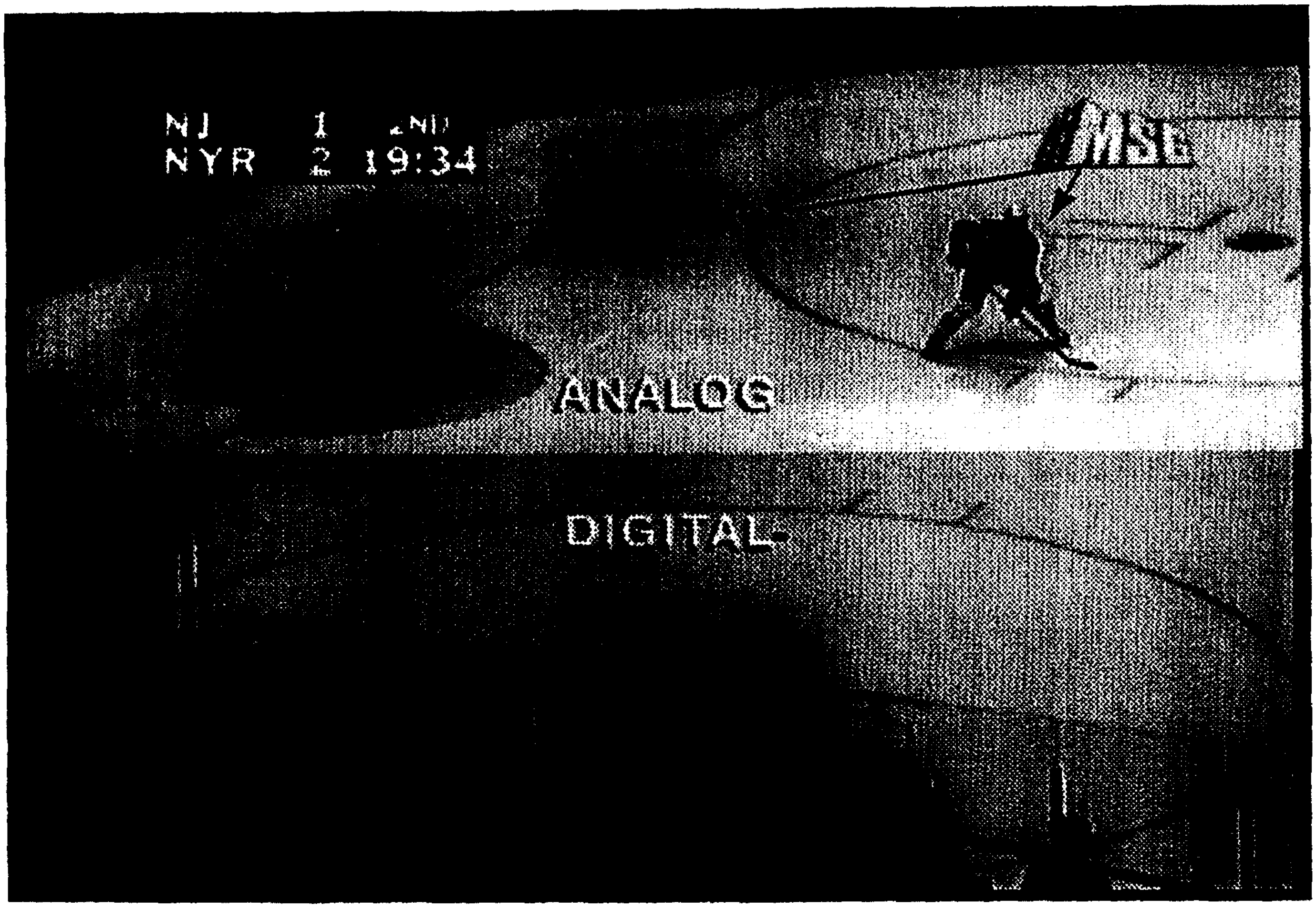
Picture Quality of Analog vs. Digital (9 Mbps, 3/4 FEC) Transmission for Case 1: Direct Line-of-Sight



Test Case 2:

The second case, moderate multi-path transmission, is representative of typical ENG operating conditions in major urban cities, such as New York City where buildings are commonplace obstructions to obtaining direct line-of-sight transmission. The ENG truck was still in the same location as in the first case, but the antenna was moved to 45 degrees off of true North so that at least one bounce was introduced in the path. Figure 12 shows the second test geometry of the signal bouncing off a building located approximately behind the ENG truck. The received signal measure was lower than the first case but still quite strong. The resulting analog signal showed noticeable ghosting artifacts and color shifting. The quality of this analog signal was considered a borderline usable picture for broadcasting. The digital signal, on the other hand, had no problem locking up and performed perfectly with no ghost or indication of multi-path in the picture for all test configurations as indicated in Case 2 split screen picture and table.

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Case 2: Moderate multi-path (~180 degree Bounce Shot)

Borderline Quality / Moderate Analog Signal
Very Good Digital Picture

Figure 12

Test Results for Case 2: Moderate multi-path

Mode	Bit Rate	FEC	BW	Rcv. Signal Level
Analog FM			17 MHz	-56 dBm
Digital	9 Mbps	3/4	8.5 MHz	-60 dBm
	10.5 Mbps	7/8	8.5 MHz	-60 dBm
	12.5 Mbps	3/4	12 MHz	-60 dBm
	15 Mbps	7/8	12 MHz	-60 dBm

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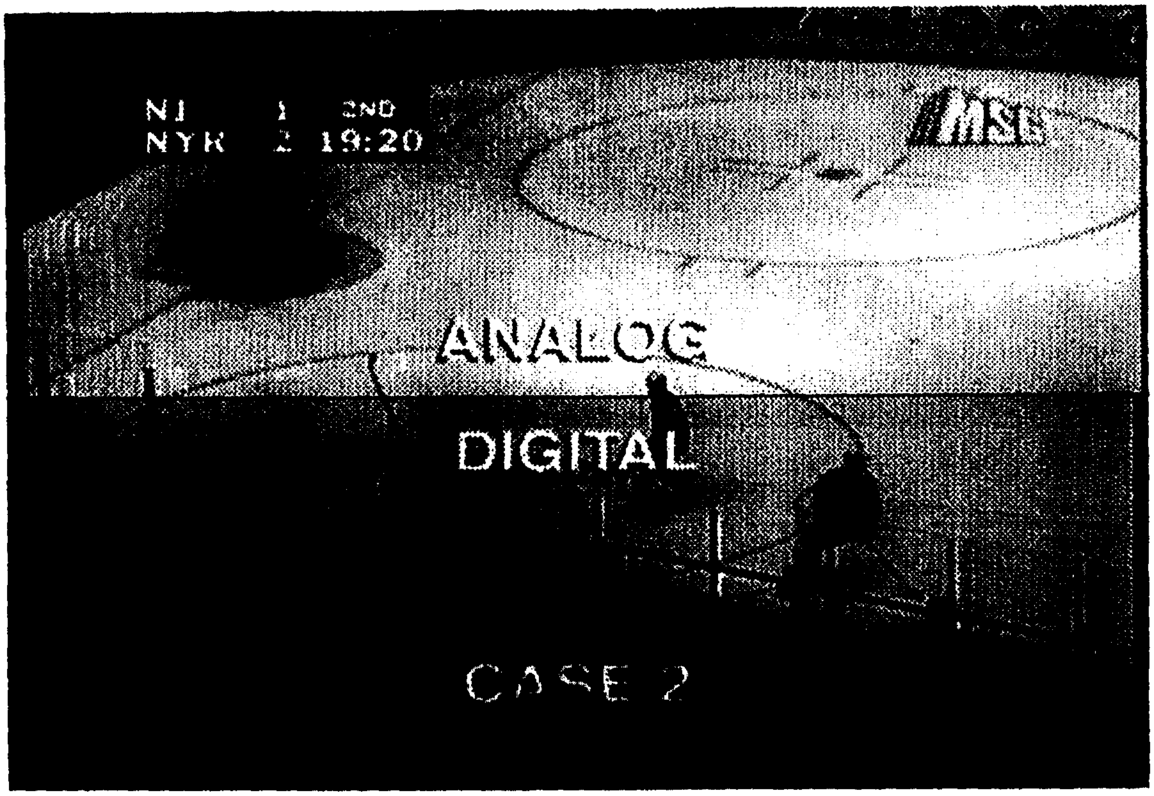
Picture Quality of Analog vs. Digital (9 Mbps, 3/4 FEC) Transmission for Case 2: Moderate multi-path



Test Case 3:

The third case tested extreme multi-path interference comprising of multiple reflections and scattering from buildings and possibly even moving vehicles. Here the ENG truck antenna aimed in the general direction toward the west side of Central Park as shown in Figure 13. The resulting transmitted analog signal was severely degraded to the point where it was not at all usable and was so bad that a frame synchronizer had to be used to receive the picture. The analog video had significant ghosting artifacts and the audio had severe breakup. The studio reported that the picture quality was too poor to broadcast. With the digital signal using an FEC of 3/4, the IRD Decoder had no problem locking on the signal and produced a perfect picture.

The hockey picture shown below is a split image of the same video picture transmitted in both analog and digital modes. The analog signal, shown in the upper half, contains very noticeable ghosting artifacts and color distortions. The digital signal, on the other hand, located in the lower half, is a clean, well-defined picture with no multi-path or noise.

In the presence of extreme multi-path, a 7/8 FEC was clearly not enough and the resulting errors can be observed by occasional slow picture motion, checker-boarding and dropouts. As predicted, an FEC rate of at least ¾ was required to adequately recover from random errors induced by multi-path interference, and in our tests, an FEC rate of ¾ seemed sufficient to recover from most errors. This test shows how important forward error correction is and that the signal path was fully testing the capabilities of the digital signal capability to operate in the multi-path environment. The following table shows test results for other data rates and FEC done on this shot.

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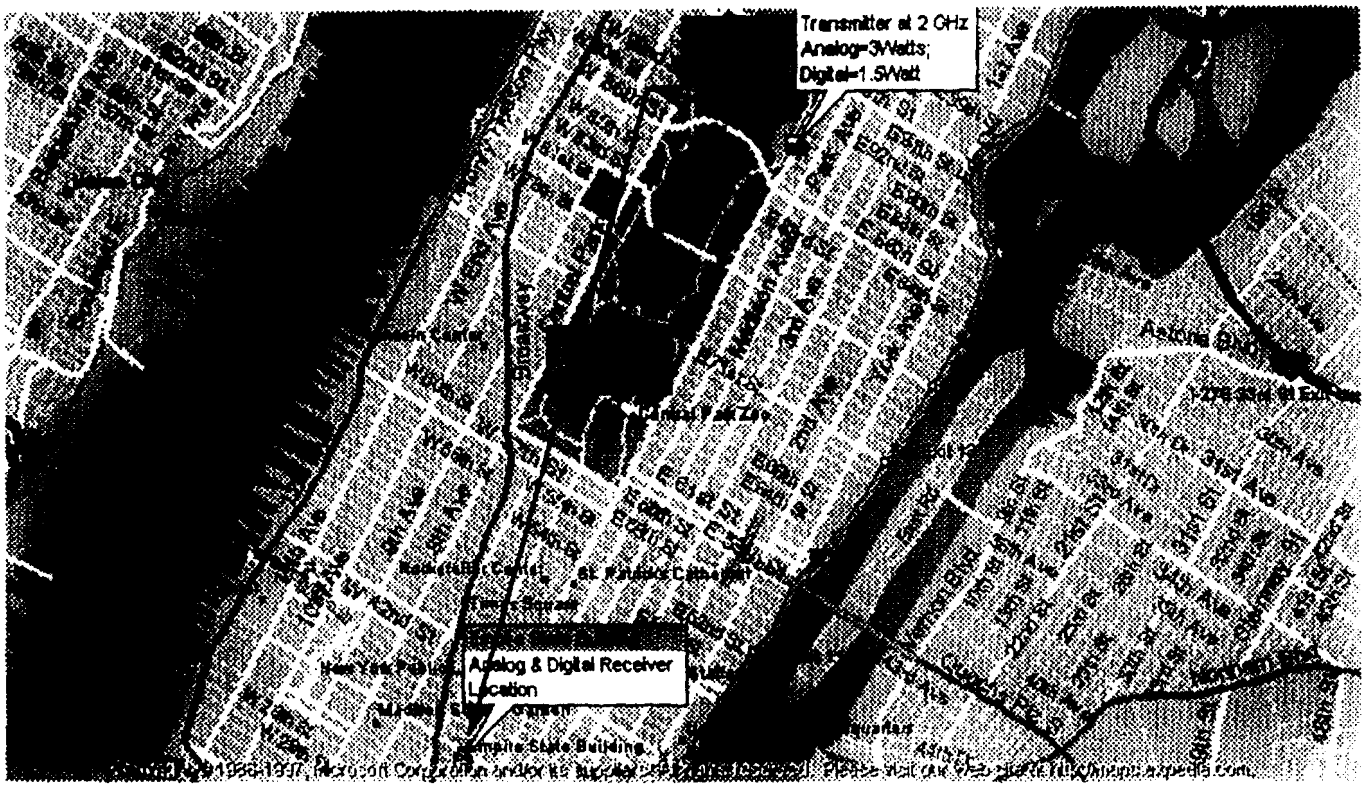
Case 3: Extreme multi-path (~ 90 degree Bounce Shot)



Unusable / Weak Analog Signal
Very Good Digital Picture

Figure 13

Test Results for Case 3: Extreme multi-path

Mode	Bit Rate	FEC	BW	Rcv. Signal Level
Analog FM			17 MHz	-70 dBm
Digital	9 Mbps	3/4	8.5 MHz	-74 dBm
	10.5 Mbps	7/8	8.5 MHz	-74 dBm
	12.5 Mbps	3/4	12 MHz	-73 dBm
	15 Mbps	7/8	12 MHz	-73 dBm
	8 Mbps	2/3	8.5 MHz	-72 dBm
	6 Mbps	1/2	8.5 MHz	-72 dBm
	4.5 Mbps	3/4	4.5 MHz	-74 dBm
	4.5 Mbps	1/2	6.5 MHz	-72 dBm

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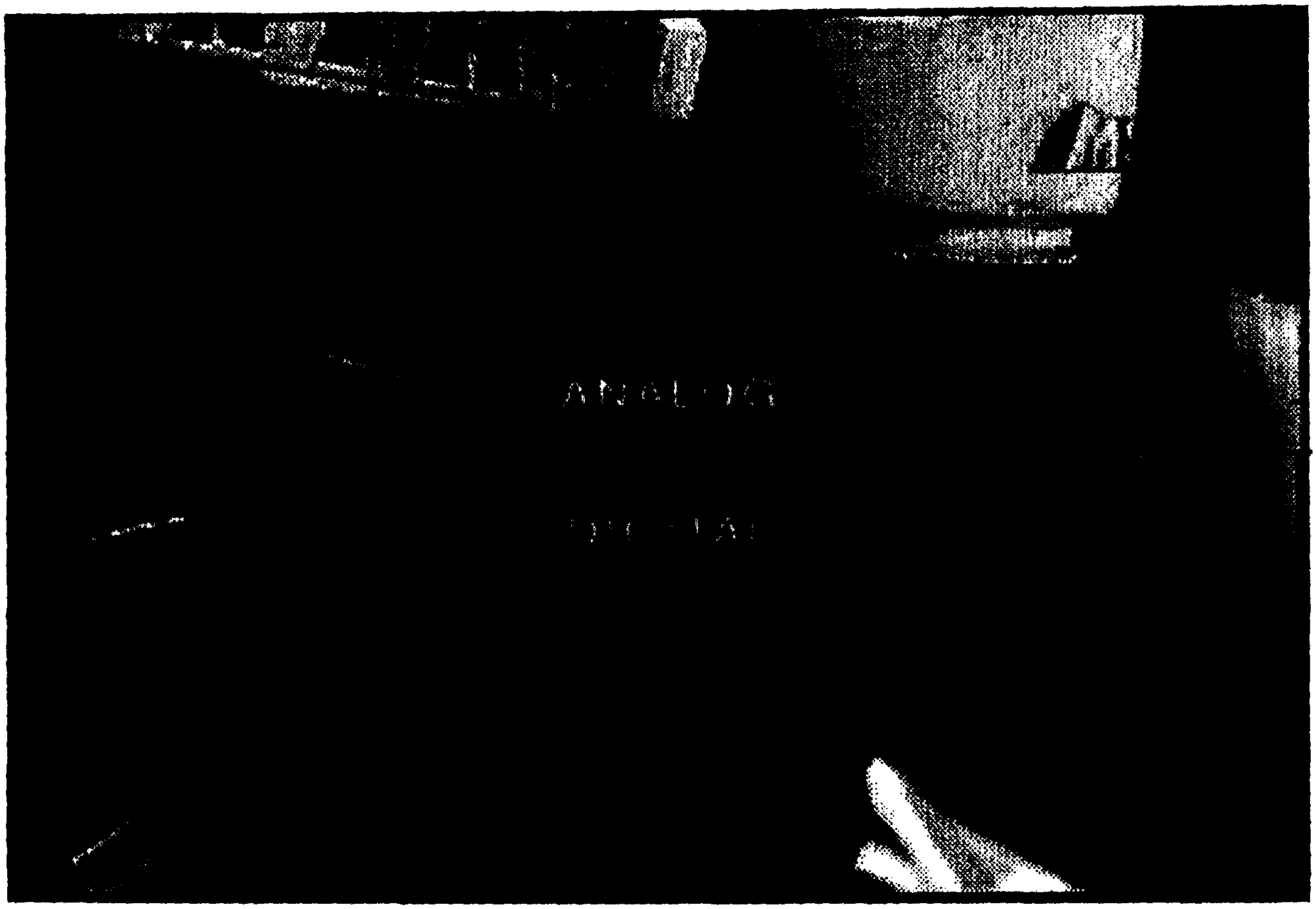
Picture Quality of Analog vs. Digital (9 Mbps, 3/4 FEC) Transmission for Case 3: Extreme multi-path



Test Case 4:

A fourth test shot was performed from in front of the WNYW studio as shown in the map of Figure 14. The Empire State Building was not visible from this location. Line of sight was blocked by numerous high rise buildings. The shot was blindly established by panning the antenna so as to shoot down an alley between two tall building and reflecting the signal off at least two other buildings. The resultant analog picture was both suitable for broadcasting. When the digital signal was transmitted, a perfect picture was consistently received.

The results of these tests, which pleasantly surprised all concerned, clearly show that Digital Video, when used for ENG in the 2 GHz band, consistently produces a picture equal to and in most cases superior to the analog transmission system.

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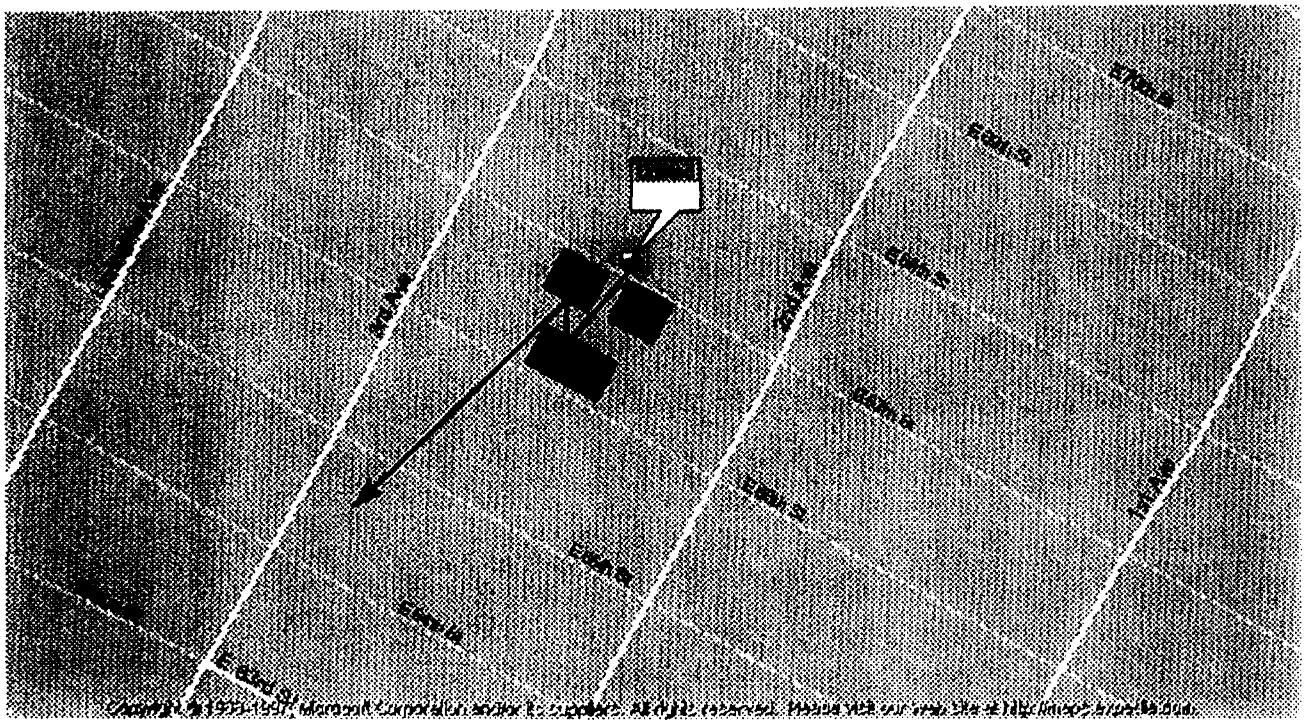
ENG Double Bounce Shot



Results -Very Noisy Analog with Multi-Path
Perfect Digital Signal
Figure 14

Summary

- **Digital transmission makes more efficient use of frequency spectrum**
  - ~8.5 MHz bandwidth as compared to 17 MHz analog (approximately double efficiency)
- **Digital transmission provides cleaner signal**
  - no ghosting artifacts
- **Digital transmission provides a superior signal in multi-path environments**
  - digital transmission allows employing techniques such as forwar error correction to provide a more robust signal over analog transmission
  - ETC...

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Conclusions:

We have presented:

- an overview of how the Digital Video Microwave technology will be applied to STL and ENG systems,
- actual laboratory and field results of tests conducted by NUCOMM using Digital Video Microwave Systems in STL and ENG applications.

These tests show that applying digital video compression, QPSK modulation, and forward error correction for STL and ENG systems can conserves frequency spectrum and yields superior video and audio quality and performance equal to and better than analog systems under both fading and multi-path environments. The digital ENG field tests specifically showed that an encoding rate of 9 Mbps yielded sufficient audio and video quality and a forward error correction rate of ¾ provided adequate error protection for all the test cases including extreme multipath interference even when using demanding source material, such as the hockey game sequence. This combination (9 Mbps, ¾ FEC) not only resulted in superior video and audio quality but also required only half the analog FM transmission bandwidths.. Higher order modulation codes for STL to conserve spectrum is advisable. Further tests are needed. The use of 16QAM modulation for ENG needs further testing. However, this and higher order codes will be more susceptible to multi-path and other interference.

The tests were performed without the use of adaptive equalization in the Digital Demodulators. Equalization was purposely not used so as to measure the uncorrected multi-path effects on such a system. The use of adaptive equalization can only further improve the performance of Digital Video systems. Further tests are planned using 16QAM and adaptive equalization.

101 Bilby Road Hackettstown, NJ 07840 Ph: 908-852-3700 FAX: 908-813-0399

COMSAT CORPORATION

Bruce A. Henoch
General Attorney

6560 Rock Spring Drive
Bethesda, MD 20817
Telephone 301 214 3347
Fax 301 214 7145
Telex 197800
Internet bruce.henoch@comsat.com

March 18, 1998

Ms. Magalie Salas, Secretary
Federal Communications Commission
1919 M Street, N.W., Room 222
Washington, D.C. 20554

RECEIVED

MAR 18 1998

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

Re: EX PARTE
ET Docket 95-18
RM - 7927
PP - 28
In the Matter of Amendment of Section 2.106 of the Commission's Rules to Allocate Spectrum at 2 GHz for Use by the Mobile-Satellite Service

Dear Ms. Salas:

COMSAT Corporation is filing this letter to apprise the Commission of the results of important tests conducted recently at COMSAT Laboratories that confirm the positions advanced by the MSS Coalition in its Petition for Partial Reconsideration, filed last year in the above-referenced proceeding.[1] The test program carried out at COMSAT Laboratories [2] clearly demonstrate that currently available "off-the-shelf" digital satellite news gathering ("SNG") compression and transmission equipment can be used as a replacement for conventional FM equipment for terrestrial Broadcast Auxiliary Service/Electronic News Gathering ("BAS/ENG") applications.

These tests are extremely important to this proceeding, because they show that, using readily-available, "off-the-shelf" digital equipment, ENG channel bandwidth can easily be reduced by a factor of two (or more) as compared to today's 17 MHz per channel--with picture quality, stability and robustness markedly superior to that provided by conventional FM ENG equipment. Consequently, the results of these tests show that when the Commission rechannelizes the BAS 2 GHz spectrum from 120 MHz to as few as 70 MHz, the reduced BAS allocation can still provide broadcasters with at least seven high-quality ENG channels in the band using digital equipment.

The tests performed at the COMSAT Laboratories were successful, via use of a wide band multipath emulator, in replicating the results of the audio-visual quality and signal robustness tests performed in New York City. The emulator was used to reproduce, under controlled conditions of the laboratory, the same three transmission conditions as found in the field tests in NYC. In

[1] *Petition for Partial Reconsideration of the MSS Coalition*, ET Docket No. 95-18 (filed May 20, 1997), pp. 9-24.

[2] *These tests reproduced the propagation conditions of field trials conducted earlier. in New York City, and confirmed the results of these tests. See Letter from Dr. John B. Payne, President, Nucomm, Inc., to Magalie Roman Salas, Secretary, FCC,* ET Docket No. 95-18 (filed Feb. 11, 1998).

addition, in a second series of tests, bit error rates of digital transmissions through the emulator were measured using the same three digital modulation techniques used in the compressed video transmission tests.

The results of the COMSAT Labs tests confirmed the data obtained in earlier field tests conducted in New York City. Our test results showed that MPEG-2 compressed digital video transmitted over a microwave carrier with QPSK modulation (either 9 Mbit/s with rate 3/4 FEC; or, 10.5 Mbit/s with rate 7/8 FEC) is a highly robust TV transmission system, producing an extremely clear and stable TV picture, even in the face of the most severe multipath propagation conditions likely to be encountered in the BAS/ENG high-rise, urban environments. Such a transmission format occupies a bandwidth/channel of only 8.5 MHz, or half that of the current BAS/ENG analog FM-TV 17 MHz channel.

Furthermore, bit error rate ("BER") measurements -- which were not made in the NYC field tests -- showed that the QPSK modulation at a bit rate of 9 Mbit/s with rate 3/4 FEC (or 10.5 Mbit/s with rate 7/8 FEC) can withstand even the most extreme multipath situation (representing multiple "building bounces" in actual field conditions), since the average BER was less than 10^{-10} (1 error in 10,000,000,000 bits) for both 3/4 FEC and 7/8 FEC (the latter with a 17% higher bit rate). Generally speaking, a BER of only 10^{-6} (1 error in 1,000,000 bits) is considered adequate link quality for transmission of MPEG-2 compressed video without degradation or artifacts. The higher-order modulation formats of 8-PSK and 16-QAM were also subjected to the same propagation conditions as QPSK. Although these formats fared well in moderate multipath, they were found to be not nearly as robust as QPSK under the worst-case, extreme multipath conditions -- for similar FEC code rates.

Attached please find a detailed description of the tests and the measurement results obtained by COMSAT Laboratories. As we note in this report, pursuant to the rules governing Ex Parte submissions in the instant 2 GHz proceeding, COMSAT will make available to the Commission upon request--for viewing by its experts--the analog FM and compressed digital video tapes recorded during our recent experiments. Any inquiries concerning the report and related matters should be addressed to Jeff Binckes at (301) 214-3263.

Yours truly,

Bruce A. Henoch
General Attorney

Enclosure

cc: Richard Smith, Bruce Franca, Roy Stewart, Regina Keeney, Robert Calaff, Rebecca Arbogast, Steve Sharkey, Sean White

Digital ENG Tests using Noisecom Microwave Emulator Performed by COMSAT Laboratories, Clarksburg, Maryland

I. Introduction

COMSAT Laboratories, a business unit of COMSAT Corporation, recently conducted laboratory tests of digital (compressed) video coupled with digital transmission techniques under propagation conditions closely representing those encountered by electronic news gathering ("ENG") links in the Broadcast Auxiliary Service ("BAS"), operating in a built-up urban environment. The main purpose of these tests was to assess and confirm the technical feasibility of using commercially available "off-the-shelf" digital satellite news gathering ("SNG") television transmission equipment as a candidate to replace conventional FM-TV for terrestrial BAS/ ENG applications. The second purpose of the test was to attempt to replicate the test conditions and results obtained by Nucomm, Inc., a manufacturer of microwave equipment, in a series of field tests conducted recently in New York City.[1]

These tests are of crucial importance to the both the MSS and broadcast industries because of recent actions by both the Commission and Congress that may result in a reduction in the amount of spectrum allocated for BAS in the 2 GHz band from 120 MHz to as few as 70 MHz. The primary conclusion obtained from these tests is that readily-available digital compression and transmission equipment has the capability of reducing ENG bandwidth needs by a factor of two (or more) while still providing improved picture quality, stability, and robustness relative to conventional FM equipment. These tests thus confirm that, using existing technology, BAS operations can be fully accommodated in an allocation of 70 MHz, and picture quality, stability, and robustness will actually be superior to that obtained today using conventional FM equipment.

II. Test Procedures

These tests were undertaken by COMSAT Laboratories in an effort to reproduce and confirm the positive results of field tests of digital ENG equipment that were conducted in New York City, in 1997, as described in an ex parte submission to the Commission. These field tests were conducted in New York City in cooperation with FOX station WNYW-TV and were carried out using a WNYW ENG truck and the station's Empire State Building Central Receive site, plus studio recording equipment and Wegener DV2000 series digital video coder/ transmitter and Integrated Receiver Decoder ("IRD") equipment. The NYC field tests were conducted under three different RF paths and associated transmission conditions: 1) direct line-of-sight transmission path, with no multipath; 2) RF path with moderate multipath, in which TV signals were bounced off buildings to complete the link; and 3) RF path with extreme multipath in which the

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[1] *See, Letter from Dr. John B. Payne, President, Nucomm, Inc., to Magalie Roman Salas, Secretary, FCC,* ET Docket No. 95-18 (filed Feb. 11, 1998).

transmit and receive antennas were intentionally misaligned to induce multiple building bounces and severe reflections (very heavy multipath).

At COMSAT Laboratories, the compressed and modulated digital video signalwas subjected to RF multipath effects, using the Noisecom MP2600 Wideband Multipath Fading Emulator acquired by the Labs in late 1997. This unit is a highly sophisticated, programmable multipath emulator, capable of handling RF signal bandwidths up to 28 MHz and a choice of Rayleigh, Rician, log-normal, Nakagami and Suzuki fading (amplitude envelope statistics) for each reflected path. This emulator was used to replicate, under controlled conditions of the laboratory, the same three transmission conditions as field tested in NYC. Specifically, in the first series of tests the audio visual quality of a 17 MHz analog FM signal was compared with the quality of a MPEG-2 digitally compressed audio and video signal occupying bandwidths smaller than that of the modulated FM-TV carrier, at bit rates ranging from 4.5 to 15 Mbps. Each of the compressed video transmissions employed digital modulation and forward error correction ("FEC") coding at selected rates for each of the particular transmission (bit) rates used.

In the second series of tests, bit error rates ("BER") of digital transmissions through the multipath emulator were measured using the same three digital modulation and FEC coding techniques as used for the audio-video comparison tests: 1) QPSK; 2) 8-PSK; and 3) 16-QAM modulation. A pseudo-random signal generator was used as the source rather than the MPEG-2 compressed digital video output data . After the pseudo-random bit stream was modulated and FEC coded, the signal was then transmitted over the three simulated RF transmission. The BER test set (Fireberd 6000A) then compared the receive digital bit stream with the transmit digital bit stream and calculated the uncorrected bit errors and the average BER.

III. Test Set-Up and Equipment

A. Multipath Emulator

The Noisecom MP2600 Wideband Multipath Fading Emulator can simulate one or two wireless communication channels that propagate over as many as 12 simulated signal paths, in which each path can be programmed with unique Doppler shift, spectral distribution, attenuation, and delay parameters. The Noisecom emulator was programmed to emulate the three multipath conditions encountered in the NYC ENG field tests, specifically: (1) direct line-of-sight transmission from ENG truck to receive site, (2) moderate multipath transmission, and (3) extreme multipath transmission.[2]

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[2] For the NYC field tests, Test Case 1 was a direct line-of-sight transmission, the "best-case" condition that resulted in a transmitted analog FM signal that produced good pictures, although there were some noticeable ghosting artifacts. Test Case 2, a moderate multipath transmission, is representative of typical ENG operating conditions in major cities where buildings are commonplace obstructions to obtaining direct line-of-sight

Appendix A contains a set of three tables giving the specific parameters used by COMSAT Labs to simulate as closely as possible each of these multipath conditions tested in the NYC field tests. These parameters were determined heuristically by adjusting the Noisecomm emulator programmable settings so as to produce ghosting and distortion of the FM-TV signal (through each of the three RF paths) until the video quality closely matched the effects seen on video tapes of the three cases in the NYC field tests.

B. Digital Codec and Modems

The digital codecs and modems used in the digital ENG lab tests were similar to the ones used in the digital ENG field tests in New York City. The baseline digital audio and video transmission system was the Wegener DV2000 series MPEG-2 digital video transmitter and IRD. The transmit/coder equipment was the DVT2000, which is a DVB compliant MPEG-2 4:2:0 encoder and QPSK modulator. Program video was digitized, 4:2:0 encoded, and multiplexed with encoded audio into a MPEG-2 transport stream at variable data rates from 2 to 15 Mbps. The data was then FEC coded using DVB-compatible concatenated coding (Convolutional inner code, Reed-Solomon outer code), then modulated by a variable rate QPSK modulator and output as a 70 MHz IF signal. The receive equipment used was the Wegener DVR2000 IRD, which is an integrated L-band (950 - 2050 MHz) receiver and decoder ("IRD unit"). Both the DVT2000 and DVR2000 equipment are currently used by TBS and NBC for digital SNG transmissions and video backhaul applications.

To test performance of higher order digital modulation for digital ENG, an external modem, the EF Data Systems SDM-8000 satellite modem, was used. This is because the Wegener digital codec contained only a QPSK modem. The SDM-8000 is a full-duplex modem supporting the following modulation modes: BPSK, QPSK, 8-PSK, and 16-QAM modulation types. Each mode can operate at several selected FEC rates and data rates up to approximately 9 Mbps (various bit rates actually tested). The supported FEC rates are 2/3 for 8-PSK modulation, 3/4 and 7/8 for 16-QAM.

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transmission. In Case 2, the antenna on the ENG truck was moved to 45 degrees off of true North so that at least one building bounce was introduced in the path. Although the resulting analog FM transmitted signal showed noticeable ghosting artifacts and color shifting, the quality was considered a borderline usable picture for broadcasting. Test Case 3 tested extreme multipath interference including fading of some reflected signals. Both the antennas on the ENG truck and the receive site were intentionally misaligned so as to maximize interference along the signal transmission path, including multiple reflections and scattering from buildings and possibly even moving vehicles. Significant ghosting and color distortions were visible, and the audio had severe breakup; the resulting analog signal quality was considered too poor to broadcast.

IV. FIRST TEST SEQUENCE: Video Quality Tests

The video quality tests compared the audio-visual quality of the analog FM signal with the quality of a digital compressed signal under similar multipath conditions encountered in the NYC field tests. Specifically, COMSAT Labs compared the quality of an analog FM signal at an allocated bandwidth of 17 MHz with an MPEG-2 digitally compressed signal at allocated bandwidths of 4.2 to 12 MHz. Since multipath transmission, especially bouncing off buildings, is common in urban ENG field operations, the Noisecom multipath emulator was the key element of equipment in the test set-up to assess the impact of various degrees of multipath on the video quality in each of the analog and digital transmission configurations. Two types of video source material were used: the first was a fast action clip from a commercial motion picture on laser disk; and the second was a high motion, high color contrast video sequence from a pre-recorded basketball game on D-2 tape.

Figure 1 shows the video test set-up configuration for analog FM transmission. The analog FM was set at 10 MHz peak-to-peak deviation for a 17 MHz allocated bandwidth.

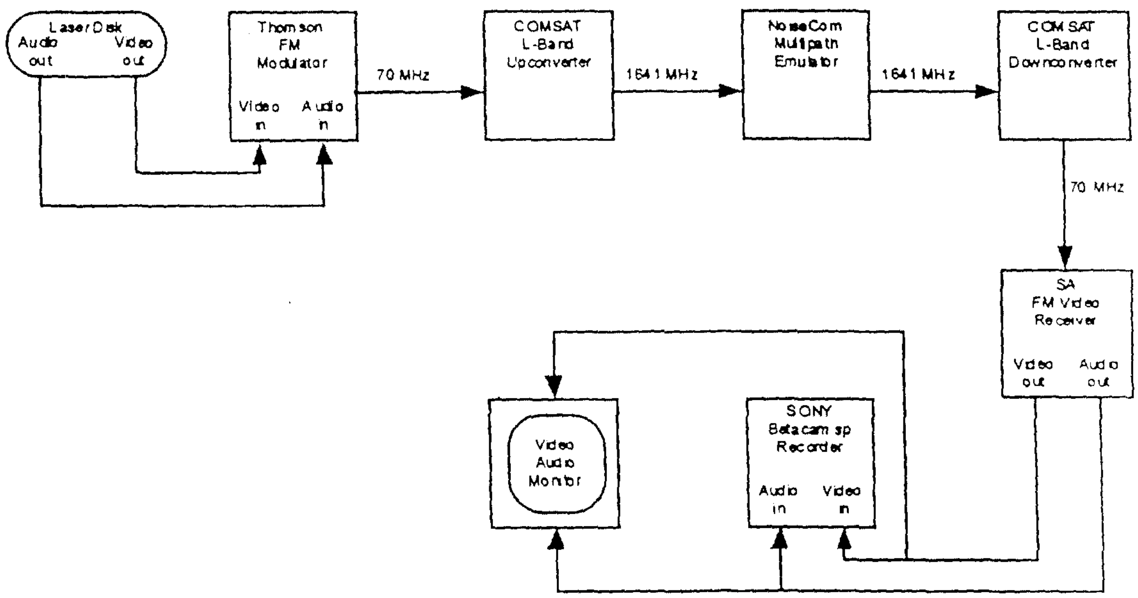

Figure 1: Analog FM Video Test Set-Up

Figure 2 shows the video test set-up configuration for digital QPSK transmission. The digital video transmission system tested data rates ranging from 4.5 to 15 Mbps using the Wegener DVT2000 encoder/transmitter. The transport bitstream was encoded at FEC rates of 1/2, 2/3, 3/4, and 7/8 and modulated using the DVT2000 internal QPSK modulator.

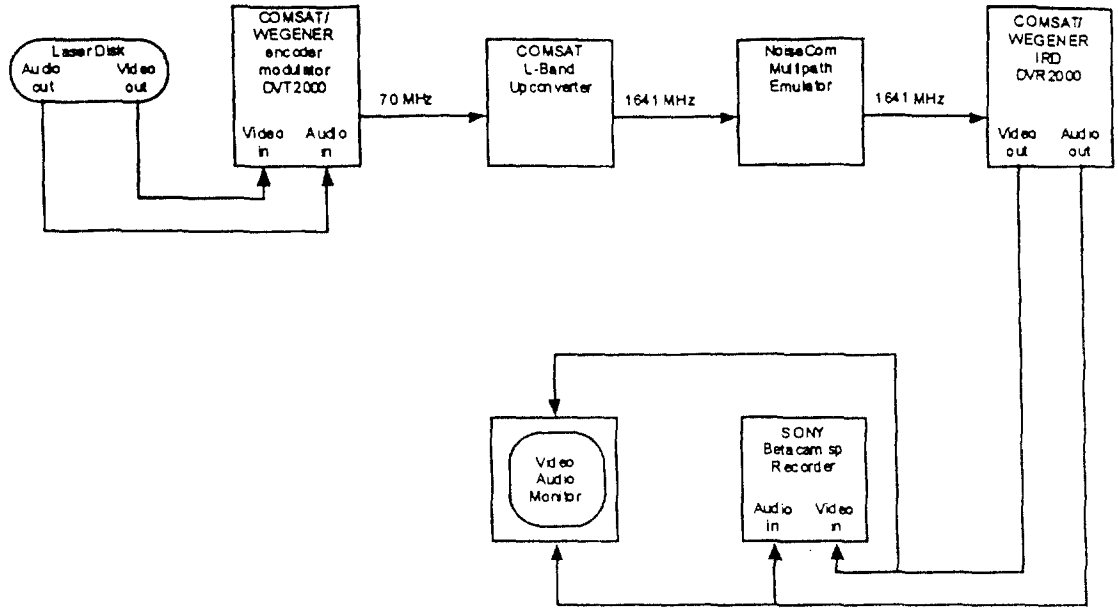

Figure 2: Digital Video Test Set-Up QPSK

Figure 3 shows the video test set-up configuration for digital 8-PSK and 16-QAM transmission. In this test set-up, the internal QPSK modulator in the DVT2000 was bypassed in order to make use of the (external) 8-PSK and 16-QAM modulators in the SDM-8000 modem. The MPEG-2 transport stream output from the DVT2000 interfaced to the SDM-8000 modem via RS-422. Due to the data rate and FEC rate limitations of the SDM-8000 modem, COMSAT Labs was constrained to the testing of the digital combinations of 6 and 7.5 Mbps, 2/3 FEC with Reed-Solomon using 8-PSK modulation, and 6 and 7.5 Mbps, 3/4 FEC with Reed-Solomon using 16-QAM modulation.

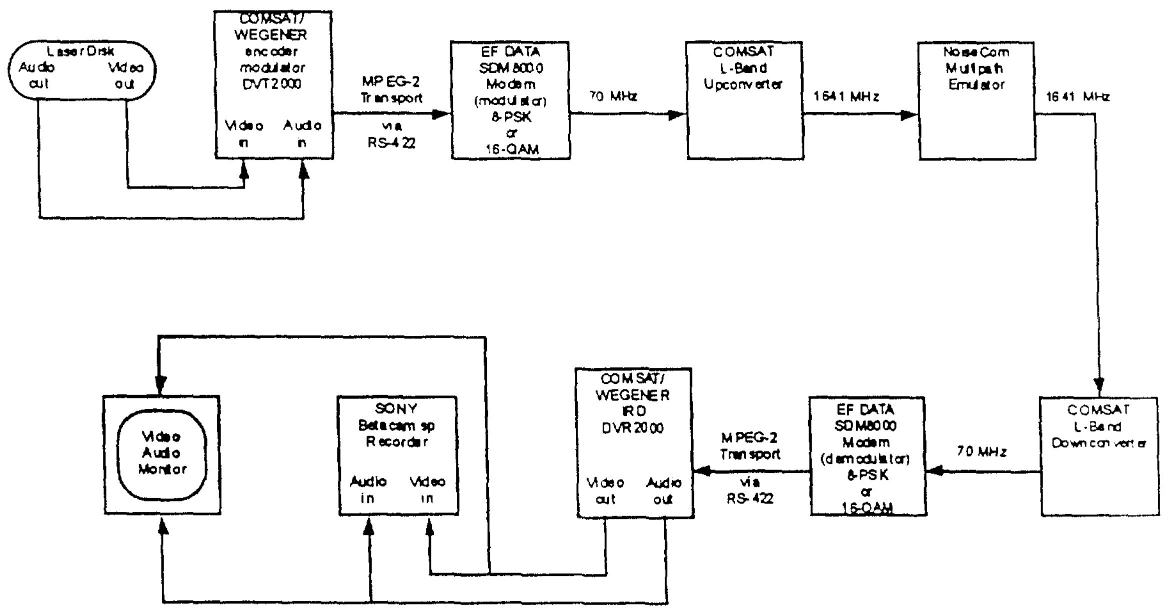

Figure 3: Digital Video Test Set-Up 8-PSK and 16-QAM

Appendix B lists all the tested digital combinations of modulation mode, transmission bit rate, FEC code rate, and nominal channel bandwidth. The resulting audio and video from the analog and digital tests was recorded onto Beta SP tape and is available for inspection.

Conclusions of First Test Sequence

- Subjective viewing of the resulting analog and digital video sequences on Beta SP tape showed that for movie material, such as an adventure-action film, the video quality starting at the lowest tested digital bit rate of 4.5 Mbps is comparable to the video quality transmitted using analog FM-TV for the "best-case" scenario of direct line-of-sight transmission, as had been carried out in the NYC field test, Test Case 1.

- For high-motion sports video material (basketball game), the minimum required data rate is approximately twice the encoding rate for movie material. Approximately 9 Mbps data rate is required to encode the 'basketball' sequence to achieve comparable video quality to the "best-case" (NYC field tests-Test Case 1) analog FM-TV case.

- In the moderate and extreme multipath cases (NYC field tests-Test Cases 2 and 3), there were visible distortions in the analog FM signal. The transmitted analog video had significant ghosting and chroma distortions; whereas, the digital signal maintained its integrity so long as there was sufficient E_b/N_o, FEC error protection and correction.

V. SECOND TEST SEQUENCE: Bit Error Rate (BER) Tests

The bit error rate performance was measured for each of the three digital modulation techniques (QPSK, 8-PSK, and 16-QAM) at selected FEC rates, all in conjunction with Reed-Solomon outer coding. The performance measurements were recorded with the Noisecom emulator added between the transmit and receive IF input and output of the SDM-8000 modem as shown in Figure 4. The measurements were the uncorrected bit errors and BER of the modem, over ~30 minute runs. The Fireberd BER Test Set generated a continuous pseudo random digital bit stream that was transmitted over the simulated RF path. It then compared the receive digital bit stream with the transmit digital bit stream and calculated the uncorrected bit error count and average BER for each test case.

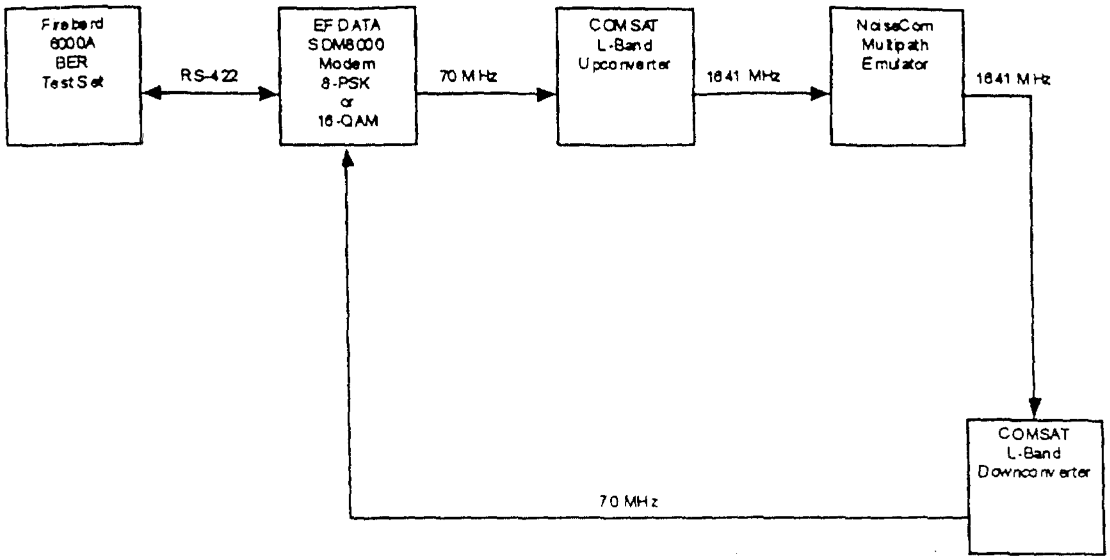

Figure 4: BER Measurement Test Set-Up

Table 1 below shows the BER measurements for the different coding configurations under each of the three NYC field test conditions (NYC field tests-Test Cases 1, 2, & 3).

Modulation	FEC	Case	Bit Error Count	Avg. BER
QPSK	¾	1	0	0 E -10
		2	0	0 E -10
		3	0	0 E -10
QPSK	7/8	1	0	0 E -10
		2	0	0 E -10
		3	0	0 E -10
8-PSK	2/3	1	0	0 E -10
		2	0	0 E -10
		3	6.5 E +8	4.7 E -2
16-QAM	3/4	1	0	0 E -10
		2	0	0 E -10
		3	5.4 E +9	4.05 E -1

Table 1: BER Measurements

Conclusions of Second Test Sequence

- As expected, QPSK is more robust than the higher order 8-PSK and 16-QAM digital modulations techniques for digital ENG. Even in the most extreme multipath case (NYC field test-Test Case 3), the average BER was 10^{-10} for QPSK modulation with both 3/4 and 7/8 FEC rates, as compared to a substantially worse average BER of 4.7 x 10^{-2} for 8-PSK with 2/3 FEC and a BER of 4.05 x 10^{-1} for 16-QAM with 3/4 FEC.

- Note however that all three digital modulation techniques maintained an average BER of 10^{-10} in the moderate multipath condition (NYC field test- Test Case 2). Since this multipath condition is more representative of an actual ENG multipath transmission environment than the extreme multipath scenario (NYC field test-Test Case 3), higher order modulation schemes such as 8-PSK and 16-QAM might still be considered viable options for digital ENG -- the advantage being higher bandwidth efficiency.

- Actual BER performance on the simulated microwave links will vary slightly, depending on modem manufacturer. It should be noted that the EF Data Systems SDM-8000 modem is a somewhat higher-performance modem than the internal QPSK modulator included internally in the DVT2000 coder/transmitter and the corresponding QPSK demodulator included in the DVR2000 IRD unit.

VI. Overall Conclusions of COMSAT LAB's Measurement Program

COMSAT Laboratories conducted digital ENG lab tests in order to evaluate to the digital ENG field tests conducted in September 1997 in New York City. COMSAT's purpose was to conduct video-audio quality and signal robustness tests in the presence of different multipath environments using the Noisecom multipath emulator to simulate the same three test conditions present in the NYC field tests. The following two test sequences were conducted: 1) audio visual quality comparison of a 17 MHz analog FM-TV signal to a digitally compressed MPEG-2 video at bit rates ranging from 4.5 to 15 Mbps, with selected Forward Error Correction (FEC) coding rates and three different digital modulation types: QPSK, 8-PSK, and 16-QAM ; and, 2) link robustness tests, consisting of bit error rate (BER) measurements using the Fireberd BER Test Set and the EF Data Systems SDM-8000 modem with QPSK, 8-PSK, and 16-QAM.

The test results show that it is technically feasible to use digital equipment such as the DV2000 series MPEG-2 digital video transmitter and IRD with either internal QPSK modem or external SDM-8000 modem—equipment currently used for digital SNG applications--for digital ENG transmission as well. An 8.5 MHz to 10 MHz ENG channel spacing in an overall BAS spectrum allocation of 70 MHz or less is quite feasible using readily available, "off-the-shelf" digital equipment. For example, a 10 MHz channel spacing provides ample bandwidth and guard band in which numerous configurations of transmission bit rate and FEC code rate can be applied. Depending on the specific requirements of the TV station, it can be configured with standard MPEG-2 main level, main profile codecs and QPSK modulators or can be configured with higher bit rate codecs and higher order digital modulation schemes. However, nominally, a digital channel configured with an MPEG-2 compressed 9 Mbps data rate, 3/4 FEC with Reed-Solomon outer coding, and QPSK modulation appears to be the best digital combination that provides excellent audio visual quality while ensuring sufficient robustness for the most severe multipath conditions that would be encountered in actual ENG field operations. These tests have shown that digital signals can be very robust and can withstand significant, heavy multipath interference before the demodulator reaches the 'cliff-point' or threshold. Similar to codec equipment, modem performance varies somewhat with manufacturer. For example, the EF Data Systems SDM-8000 modem is a higher performance modem than the internal QPSK modulator in the DVT2000 codec; and, consequently has slightly better BER performance in the presence of multipath. As shown by the BER test results of the SDM-8000 modem, higher order modulation schemes; such as, 8-PSK and 16-QAM may nonetheless be viable options for digital ENG transmission.

COMSAT would like to make the analog FM and Compressed Digital Video tapes recorded during our experiments at our laboratories available to the Commission for viewing by its experts.

Appendix A: Noisecom Settings to Simulate NYC Multi-path Conditions

Table A1: Noisecom Settings for Case 1 (Direct Line-of-Sight)

Path	Fading	Loss (dB)	Delay (μsec)	Offset (deg.)
1	-	0	16.1	58.5
2	-	25	16.6	108.5
3	-	27	17.2	158.4

Analog receive signal level (prior to receiver) ~ -26 to -27 dBm
Digital receive signal level (prior to IRD) ~ -56 to -58 dBm

Table A2: Noisecom Settings for Case 2 (Moderate Multi-Path)

Path	Fading	Loss (dB)	Delay (μsec)	Offset (deg.)
1	-	0	16.6	108.5
2	-	27	17.7	28.4
3	-	28	18.3	78.3
4	-	25	18.8	128.3
5	-	25	19.97	48.2
6	-	25	20.4	98.1

analog receive signal level was ~ -46 to -47 dBm

Table A3: Noisecom Settings for Case 3 (Extreme Multi-Path)

Path	Fading	Doppler (Hz)	Loss (dB)	Delay (μsec)	Offset (deg.)
1	-	-	0	18.8	128.3
2	-	-	20	19.3	178.2
3	-	-	15	19.9	48.2
4	-	-	20	20.4	98.1
5	Log-normal	.7	16	23.9	148.1
6	Log-normal	1.0	20	26.5	18.0

In analog case, measured signal level at L-band downconverter (prior to Noisecom) is approximately equal to a signal level of -49 dBm
In digital case, measured receive signal level is still -56 to -58 dBm

Appendix B: Video Tapes

Tape #1: Simulation of NYC Digital ENG tests
Source material: Commercial action film, Track #41, 1.5 minutes, Laserdisk
Modulation: QPSK, DVT2000 coder/transmitter and DVR2000 IRD unit

Case	Mode	Bit Rate & FEC	Allocated BW	Beg. Timecode
1	Analog FM	-	17 MHz	00:00
	Digital QPSK	(9 Mbps, 3/4)	8.5 MHz	02:00
		(10.5 Mbps, 7/8)	8.5 MHz	04:00
		(12.5 Mbps, 3/4)	12 MHz	06:00
		(15 Mbps, 7/8)	12 MHz	08:00
2	Analog FM	-	17 MHz	10:00
	Digital QPSK	(9 Mbps, 3/4)	8.5 MHz	12:00
		(10.5 Mbps, 7/8)	8.5 MHz	14:00
		(12.5 Mbps, 3/4)	12 MHz	16:00
		(15 Mbps, 7/8)	12 MHz	18:00
3	Analog FM	-	17 MHz	20:00
	Digital QPSK	(9 Mbps, 3/4)	8.5 MHz	22:00
		(10.5 Mbps, 7/8)	8.5 MHz	24:00
		(12.5 Mbps, 3/4)	12 MHz	26:00
		(15 Mbps,7/8)	12 MHz	28:00

Table B1: Video Tape #1 Recordings

Tape #2: Additional Transmission rates and FEC Code Rates (Not tested in NYC)
Source material #1: Commercial action film on Laserdisk
Source material #2: Basketball on D-2
Modulation: QPSK, DVT2000 coder/transmitter and DVR2000 IRD unit

Case	Mode	Bit Rate & FEC	Allocated BW	Beg. Timecode
3	Digital QPSK	(8 Mbps, 2/3)	8.5 MHz	00:00
	(True Lies)	(6 Mbps, 1/2)	8.5 MHz	02:00
		(4.5 Mbps, 3/4)	4.2 MHz	04:00
		(4.5 Mbps, 1/2)	6.3 MHz	06:00
		(10.5 Mbps, 3/4)	10 MHz	08:00
		(9.5 Mbps, 2/3)	10 MHz	10:00
		(7 Mbps, 1/2)	10 MHz	12:00
	Basketball	(8 Mbps, 3/4)	7.5 MHz	14:00
		(9 Mbps, 3/4)	8.5 MHz	16:00
		(10.5 Mbps, 3/4)	10 MHz	18:00
		(12.5 Mbps, 3/4)	12 MHz	20:00
		(15 Mbps, 3/4)	14 MHz	22:00

Table B2: Video Tape #2 Recordings

Tape #3: Higher-Order Modulation (8-PSK & 16 QAM) Tests
Source material: Basketball on D-2
Modulation: EF Data Systems SDM8000 modem (8-PSK, 16-QAM)
Note: Reed Solomon FEC on for all cases

Case	Mode	Bit Rate & FEC	Allocated BW	Beg. Timecode
1	Analog FM	-	17 MHz	00:00
	Digital (8-PSK)	(7.5 Mbps, 2/3)	7.3 MHz	02:00
		(6 Mbps, 2/3)	5.8 MHz	04:00
	Digital (16-QAM)	(6 Mbps, 3/4)	4 MHz	06:00
		(7.5 Mbps, 3/4)	5 MHz	08:00
2	Analog FM	-	17 MHz	10:00
	Digital (8-PSK)	(7.5 Mbps, 2/3)	7.3 MHz	12:00
		(6 Mbps, 2/3)	5.8 MHz	14:00
	Digital (16-QAM)	(6 Mbps, 3/4)	4 MHz	16:00
		(7.5 Mbps, 3/4)	5 MHz	18:00
3	Analog FM	-	17 MHz	20:00
	Digital (8-PSK)	(7.5 Mbps, 2/3)	7.3 MHz	22:00
		(6 Mbps, 2/3)	5.8 MHz	24:00
	Digital (16-QAM)	(6 Mbps, 3/4)	4 MHz	26:00
		(7.5 Mbps, 3/4)	5 MHz	28:00

Table B3: Video Tape #3 Recordings